CARBOWASTE

Treatment and Disposal of Irradiated Graphite and Other Carbonaceous Waste

Grant Agreement Number: FP7-211333

Technical Report T-1.5.5
Application of MCDA on Dismantling Alternatives of Ignalina NPP (V1)

Author(s):
Povilas Poskas; LEI
Gintautas Poskas; LEI

Date of issue of this report: 25/03/2013

Project co-funded by the European Commission under the Seventh Framework Programme (2007 to 2011) of the European Atomic Energy Community (EURATOM) for nuclear research and training activities		
Dissemination Level		
PU	Public	
RE	Restricted to the partners of the CARBOWASTE project	X
CO	Confidential, only for specific distribution list defined on this document	

Start date of project: **01/04/2008** Duration: **60 Months**

Distribution list

Person and organisation name and/or group	Comments
CARBOWASTE participants	

CARBOWASTE		
Work package: 1 **Task:** 1.5	**CARBOWASTE document no.:** CARBOWASTE-1303-T-1.5.5 (e.g. May 2008 as date of issue: 0805)	**Document type:** T=Technical Report
Issued by: LEI (LT) **Internal no.:** CW1303-Deliverable-T-1-5-5-final		**Document status:** Final

Document title
Application of MCDA on Dismantling Alternatives of Ignalina NPP (V1)

Executive summary

Based on CARBOWASTE Report T-1.4.1, where MCDA Tools/Methodologies were proposed, Analytic Hierarchy Process (AHP) method (one of proposed methods) was chosen for analysis of equipment dismantling alternatives in Building V1. Also qualitative and quantitative criteria tree proposed in the CARBOWASTE Report was adopted to suit Building V1 needs

In order to perform different alternatives analysis, some of the important outputs (the global manpower needed, the global dose, the global cost, consumables needed, discharges, time schedule, etc.) are necessary. To provide and justify these outputs a corresponding evaluation of the alternatives has to be performed. For the calculation for these outputs/quantitative criteria values for different equipment dismantling alternatives a computer tool DECRAD developed by LEI was used.

Revisions

Rev.	Date	Short description	Author	Internal Review	Task Leader	WP Leader
00	dd/mm/yyyy	Issue	Name, Organisation *Signature*	Name, Organisation *Signature*	Name, Organisation *Signature*	Name, Organisation *Signature*
01	21/03/2012	First issue	Poskas LEI	Poskas LEI	Banford NNL	Banford NNL
02	25/03/2013	Final issue	Poskas LEI	Poskas LEI	Banford NNL	Banford NNL

Abbreviations

MCDA	Multi-Criteria Decision Analysis
AHP	Analytic Hierarchy Process
LEI	Lithuanian Energy Institute
SSS	Spent Sealed Sources
EW	Exempt waste
VLLW	Very Low Level Waste
L/ILW	Low/Intermediate Level Waste
WS	Waste Stream
CR	Consistency ratio

Table of contents

Figures

Tables

1 Introduction

The Ignalina NPP is located in the north-eastern part of Lithuania, near the borders of Latvia and Belarus. The Ignalina NPP was operating two (graphite moderated) RBMK-1500 reactors. Unit 1 and Unit 2 were closed at the end of 2004 and at the end of 2009 respectively. So, now preparation for the dismantling of the systems is ongoing.

The analysis of different equipment dismantling alternatives of Building V1 at Ignalina NPP, where waste streams, safety and environmental criteria are added to the usual economic, technical, duration and social criteria demands the use of powerful decision making techniques. The traditional single decision-making approach is no longer able to handle these problems. The multiplicity of criteria, and the involvement of several decision makers in the decision procedure makes multi-criteria decision analysis (MCDA) a valuable tool.

Based on CARBOWASTE Report T-1.4.1, where MCDA Tools/Methodologies were proposed, Analytic Hierarchy Process (AHP) method (one of proposed methods) was chosen for analysis of equipment dismantling alternatives in Building V1. Also qualitative and quantitative criteria tree proposed in the CARBOWASTE Report was adopted to suit Building V1 needs.

In order to perform different alternatives analysis, some of the important outputs (the global manpower needed, the global dose, the global cost, consumables needed, discharges, time schedule, etc.) are necessary. To provide and justify these outputs a corresponding evaluation of the alternatives has to be performed. For the calculation for these outputs/quantitative criteria values for different equipment dismantling alternatives a computer tool DECRAD developed by LEI was used.

2 Building V1 at Ignalina NPP

Building V1 is located on the west side of Unit 1 (Figure 1). It is quite a big building (the volume based on overall dimensions is 50800 m^3) with more than 250 rooms located at 9 levels. Auxiliary systems located in Building V1 are:

- A part of the reactor gas circuit;
- Gas discharges purification system;

- Main circulation circuit maintenance cooling tanks system;
- A part of the emergency core cooling system;
- Different components of ventilation systems.

Figure 1: Building V1 outside and inside view

Not all systems in the building can be dismantled at the same time. Some of them are still necessary for safety purposes in Unit 1 and will be also needed for safety assurance during the dismantling. Thus, the dismantling works can be divided into three phases:

- Phase 1. Basically all the systems will be dismantled except the special ventilation system 1WZ56 (during this phase it will have to function properly), electric cables and components located in the concrete structures;
- Phase 2. Ventilation system 1WZ56 and all the electric cables will be dismantled simultaneously with systems in building A1 (reactor building);
- Phase 3. After the destruction of building V1 all the components which were located in concrete structures (EW) will be pulled out from the rubble.

Phase 1 was planned to start at the beginning of 2012 (but it is already some delay), and Phase 2 is planned to be started after 11 years, i.e., in 2023, during the dismantling of the system in building A1.

The total mass of the components to be dismantled is ~1283 tones. Mass distribution for different phases can be seen in Figure 2. During Phase 1, the mass of the dismantled equipment is approximately 47 %, and during Phase 2 it equals to 34 % of all the equipment mass of building V1. The mass of the waste during Phase 3 (EW) equals almost to one fifth, i.e., ~244 tones of the overall dismantling mass.

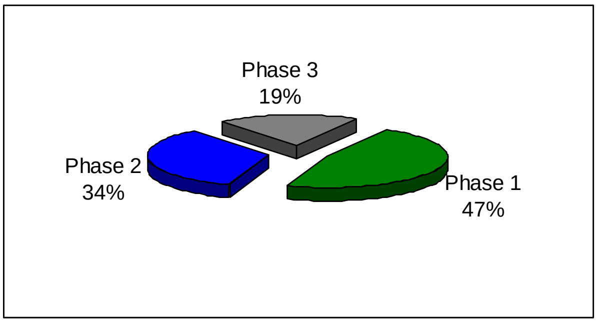

Figure 2: Primary mass by phases in Building V1

In this report Phases 1 and 2 are analysed. Phase 3 will be analysed later when destruction project for building V1 is prepared.

The distribution of the dismantled components by material for Phase 1 and 2 is shown in Figure 3. The biggest part (50 %) of the dismantled components during Phase 1 consists of metal materials, i.e., steel (38 %) and stainless steel (22 %). The remaining part of the components is consisted of concrete, active carbon from filters, etc. The biggest part of the dismantled components during Phase 2 also consists of metal materials (78 %). 12 % of the components are of mixed materials and the rest 10 % consists of insulation, etc.

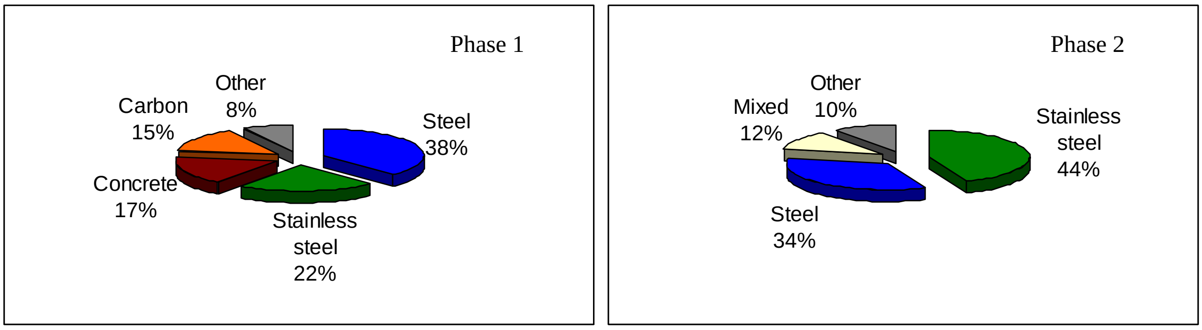

Figure 3: Primary mass by material in Building V1

The analysis of the distribution of the dismantled masses by waste types has shown (Figure 4) that during Phase 1 the total mass of dismantled components consists of 60 % of VLLW, 40 % of exempt waste (EW) and only <0.1 % of LLW. In Phase 2 there is similar distribution of masses by waste types. The difference is that LLW mass in Phase 2 is a little higher than in Phase 1. Also during this phase the components that contain spent nuclear sources (SSS) will be dismantled as well. However, the mass of SSS components is very low.

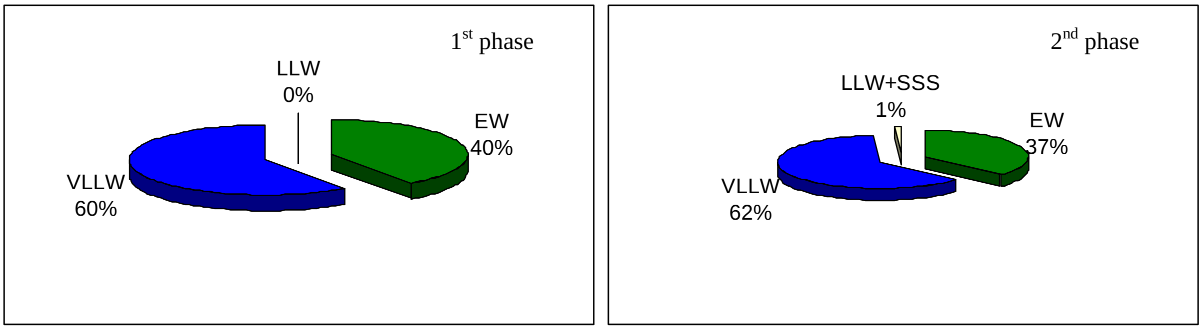

Figure 4: Primary mass by waste classes in Building V1

3 Methodology

3.1 Quantitative data calculation tool

For the analysis of nuclear plants decommissioning activities computer programs such as Cora-Calcom [0], Omega [2], Dexus [3], etc. are used. They are orientated to calculation of the data for preparation of the Decommissioning Plans.

For preparation of the systems dismantling project more detailed information is necessary, so for analysis of different equipment dismantling alternatives in Building V1 DECRAD tool [4] (output data is presented in Table 1) was used. DECRAD was developed at LEI by Nuclear Engineering Laboratory:

- For calculation of necessary data for assessment of different strategies/alternatives;
- To support detailed dismantling projects of separate buildings;
- Integrated waste disposal planning for the whole nuclear facilities.

Table 1: DECRAD outputs

Worker Safety (Radiological)	Cost
Collective dose [man Sv]	Labour cash flow (with OH) [Euro]
Individual dose [mSv]	Consumables cash flow [Euro]
Resource Usage	Procurement cash flow [Euro]
Needed manpower by qualification [man-day]	Waste management cash flow [Euro]
Total needed manpower [man-day]	Preparatory activities cash flow [Euro]
Consumables [kg or units]	Waste Activity Data
Non-Radiological Discharges	Liquid rad. Waste [Bq]
Chemical into the lake [m^3]	Solid to Landfill (primary and secondary waste) [Bq]
Radiological Discharges	
Liquid into the lake [m^3 or Bq]	Solid waste to NSR (primary and secondary waste) [Bq]
Aerosols to atmosphere [m^3 or Bq]	
Hazard Potential	Bituminised waste [Bq] and etc.

Hazardous/toxic inventories	
Other	
Inventory data (primary waste by rooms, systems, types, material, phases, etc.) Radiological data (decontamination factor, waste class, nuclide vector, etc.) Waste management data (primary and secondary waste by: disposal ways, stages, tools; primary and secondary waste packaging data; etc.) Scheduling data (project duration, work breakdown structure (WBS), etc.) Data flows (masses, packages and doses by month)	

The structure of the computer code is presented in Figure 5. DECRAD has been developed as a tool that provides the transition of planning results into project management measures. So the tasks of planning and calculation as well as documentation and the project controlling are simplified considerably.

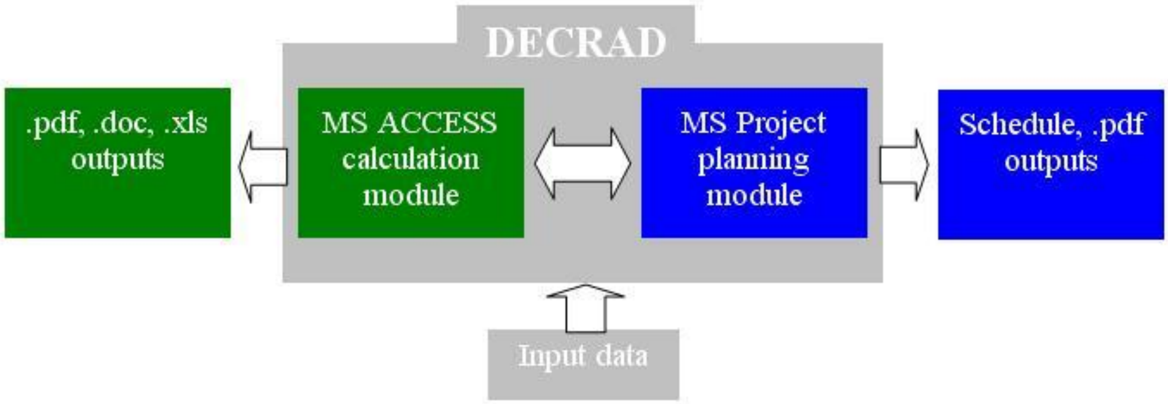

Figure 5: Simplified structure of DECRAD

DECRAD is used to register and evaluate all the data required for activity planning (masses, technical component data, room data, radioactivity levels including contamination and activation as well as dose rates). The collection of data on the inventory to be removed/dismantled is one of the most important aspects in planning.

The main input data was based on the Building V1 Equipment technical data list. This list is a complete list of process equipment and other components (auxiliary structures, etc.) located in Building V1 with the information on their main physical characteristics. The technical data on every Building V1 component contains the following:

- The building number, unit, room number;
- The component name;
- The component type;

- The process tagging;
- The material the component is made of;
- The number of components;
- Number of the D&D phase assigned to the component, etc.

In order not to operate with each single component, all components in Equipment technical data list were grouped into waste streams. Such approach allowed to group/generalize the types of equipment/components with the same features:

- Technique for dismantling, decontamination, etc;
- Packaging;
- Disposal way, etc.

3.2 MCDA technique

Based on CARBOWASTE report, where MCDA Tools/Methodologies were proposed, Analytic Hierarchy Process (AHP) method (one of proposed methods) was chosen for the analysis of equipment dismantling alternatives in Building V1.

AHP is applied by breaking down an unstructured problem into component parts. Hierarchical orders are arranged by forming hierarchical structures with goal (objective) at the top of the hierarchy, criteria affecting the decision at the intermediate level, and decisions options (alternatives) at the bottom of the hierarchy. The decision-makers are then guided through a series of pair-wise comparison judgments to express relative strength or intensity of the elements impact in the hierarchy. These judgments, represented by assigning numerical values, are then synthesized in the use of eigenvectors to determine which variables have the highest priority.

There are a number of software packages in the market that use AHP method for calculation, e.g., EXPERT CHOICE, HIPRE3+, HIVIEW (MACBETH), etc. In this case the calculations were performed by the universal software, i.e., MATLAB and MS EXCEL.

3.3 Alternatives

Two equipment dismantling alternatives of Building V1 were formulated. These are explained in detail in Table 2.

Table 2: Equipment dismantling alternatives of Building V1

Alternative	Description
A1	Mechanical decontamination is performed for contaminated dismantled components, if it is possible. They are decontaminated to EW level. The secondary waste and components that cannot be decontaminated to EW level, whether are disposed at the VLLW repository or transported to the treatment facility for further treatment and disposal in the near surface disposal facility for L/ILW.
A2	Mechanical decontamination of the contaminated dismantled components is not performed. VLLW is disposed into VLLW repository while L/ILW is transported to treatment facility for further treatment and disposal in the near surface disposal facility for L/ILW.

During the analysis it was considered that the dismantling works are performed by two groups of workers simultaneously. The first group uses only cold cutting tools (scissors, hydraulic scissors, pendulum saw, angular grinder, etc.) while the second group uses cold and hot cutting tools (plasma-cutting tool). Hot cutting tools are necessary because there are thick-walled and complex geometry components.

Also it was considered that there is a third group of workers who transport the dismantled equipment to the decontamination (if necessary) and monitoring zones.

3.4 Criteria

Qualitative and quantitative criteria tree proposed in the CARBOWASTE Report was adopted to suit Building V1 needs (Table 3).

Table 3: Criteria to measure dismantling alternatives performance in Building V1

Criteria	Sub-criteria	Description	Type	Units
W1. Waste streams	W1.1. Primary waste ratio	The criterion compares the relation between the overall primary waste mass and primary exempted waste mass.	Quan.	%
	W1.2. Secondary waste ratio	The criterion compares the relation between the overall secondary waste mass and secondary exempted waste mass.	Quan.	%

Criteria	Sub-criteria	Description	Type	Units
	W1.3. Secondary waste mass	The amount of secondary waste (metal shaves, used cutting tools, filters, abrasive, etc.) during D&D activities.	Quan.	t
E1. Econo-mic	E1.1. Initial investment	Certain equipment (lifts, cutting, decontamination, radiological measurements and electrical equipment, containers for waste disposal and transportation, etc.) must be purchased for D&D activities.	Quan.	Eur
	E1.2. Total costs	The overall expenses of the project.	Quan.	Eur
	E1.3. Spin-off	Investment will lead to spin-off opportunities not directly related to the delivery of the project. For example, metal fabrication skills used in manufacture of waste packages might allow fabrication for other customers, with associated economic benefit.	Qual.	Expert judg.
D1. Duration	D1.1. Duration of the project	The duration (months) from the start till the end of the project.	Quan.	Month
	D1.2. Manpower	Needed manpower expressed as man/day (e.g., man/day means that one man works one day or two men do the same job each half a day). The criterion evaluates the difficulty and duration of the work.	Quan.	Man/day
S1. Safety	S1.1. Radiological worker safety	Radiological (collective dose measured in man-Sv) impact is considered.	Quan.	Expert judg.
	S1.2. Conventional worker safety	Non-radiological (e.g. falls, asphyxiation, etc.) impacts are considered.	Qual.	Expert judg.
T1. Techno-logy	T1.1. Use of the existing infrastructure	The criterion evaluates how the existing infrastructure (cranes, lifts, railing, etc.) is used and how the parameters of the building are changed (destruction/building of screens, smoothing of the floor, modification/creation of new ventilation system, electricity and data networks, etc.) while dismantling equipment.	Qual.	Expert judg.
	T1.2. Technology predictability	This criterion considers the uncertainty, or ‘readiness’, associated with the technology chosen for a particular alternative. Mature technology is associated with a lower risk than completely new concepts.	Qual.	Expert judg.

Criteria	Sub-criteria	Description	Type	Units
	T1.3. Operational predictability	This criterion considers the uncertainty associated with the operational phase of a particular alternative. Uncertainty may be the result of feed variability, unreliability or equipment complexity or lack of experience with the technology.	Qual.	Expert judg.
E2. Environ-mental	E2.1. Radiological impact – man	This sub-criterion considers the impact of regulated discharges on man.	Qual.	Expert judg.
	E2.2. Radiological impact – environment	This measure compares the concentration of radioisotopes in the environment to a value which results in a broadly acceptable dose to the most vulnerable organism. When the resulting quantity is summed over all radioisotopes a measure of the impact of the radiation on the environment is obtained.	Qual.	Expert judg.
	E2.3. Resource usage	Some options may use more resources than others. Resources may include water, power, steel and concrete. 'Resources' can be combined into a single measure by considering the energy used to produce them.	Qual.	Expert judg.
	E2.4. Non radiological discharges	The impact of non-radiological discharges.	Qual.	Expert judg.
	E2.5. Local intrusion	This sub-criterion assesses the local impact of noise, traffic during construction and operations, artificial light, ground vibration and land use on man and the environment.	Qual.	Expert judg.
	E2.6. Hazard potential	The emphasis of the sub-criterion is to encourage the selection of passively safe techniques with minimum hazardous inventory, in accordance with radioactive waste management best practice.	Qual.	Expert judg.
S2. Social	S2.1. Employment level	Stability of employment. Delivery of some options will temporarily result in greater levels of employment than others. This sub-criterion considers wider economic concerns such as targeting areas of high unemployment, acquiring transferable skills and stability (rather than absolute levels) of employment.	Qual.	Expert judg.

Criteria	Sub-criteria	Description	Type	Units
	S2.2. Burden level	Burden on future generations. A problem with the criteria above is that continual delay appears to be a good option: activity decays, costs are depreciated and arisings of activity are deferred and potentially reduced. However, staff experienced in the operation of the plant retire and knowledge about the nature of the wastes is lost, buildings decay and there are moral concerns in leaving work for future generations when the benefits of the reactor operation have been experienced by the current generation. These aspects are grouped together here under this sub-criterion.	Qual.	Expert judg.

4 Results

4.1 Quantitative data

Waste streams analysis for alternative A1 in Phase 1 shows (Figure 6) that 79 % of the primary waste meets EW criteria and will be transported to FRMF. 6 % of the primary waste must be disposed of to the VLLW repository. The rest part (15 %) of the primary waste can neither be decontaminated to the EW level, nor meets the requirements of VLLW repository waste disposal criteria, so the waste must be transported to B3 (i.e., New Solid Waste Management and Storage Facilities) complex for further management and storage till the final disposal.

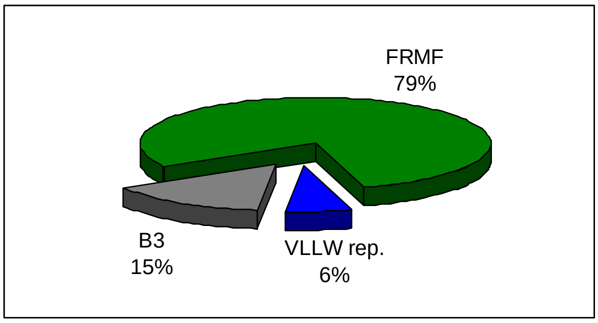

Figure 6: WS in Phase 1 for alternative A1

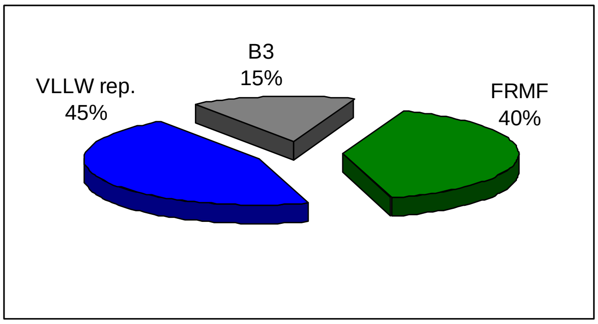

Figure 7: WS in Phase 2 for alternative A2

Waste streams analysis for alternative A2 in Phase 2 (i.e., if the dismantled contaminated components meet the requirements of VLLW repository waste disposal criteria, they are transferred right to the VLLW repository without being decontaminated) shows that only 40 % of the overall dismantled waste mass will be managed as EW and will be transported to FRMF (Figure 7). This amount of EW is two times smaller than when the dismantled components are decontaminated (Figure 6). Compared to the preceding case (when the amount was only 6 %; see Figure 6), primary waste amount to VLLW repository in this case (see Figure 7) is quite big, i.e., 45 %. Certainly, in this case the same amount of waste (15 %) is transported to the B3 complex.

WS analysis has shown that during Phase 2 for A1 alternative, 98 % (Figure 8) of the dismantled mass will be EW and only 2 % of the primary waste will be transported to radioactive waste management complexes (B3, VLLW repository).

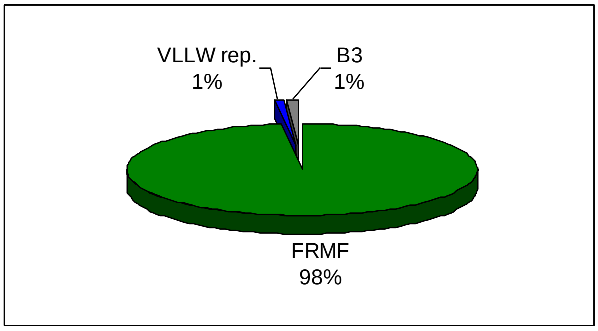

Figure 8: WS in Phase 2 for alternative A1

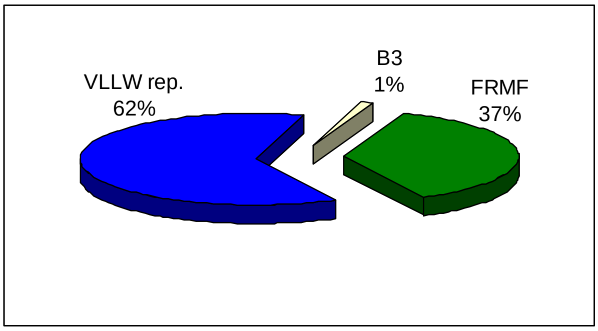

Figure 9: WS in Phase 2 for alternative A2

For A2 alternative (Figure 9), 37 % of the primary waste is EW (i.e., waste that are transportable to FRMF), while applying decontamination this amount increases more than two times (98 %; Figure 8). There is almost no primary waste that should be transported to VLLW repository for the A1 alternative while for the A2 alternative the amount of such waste is 62 % of the overall dismantled mass of the components.

Apart from the primary waste, there will certainly be the secondary waste such as metal shaves, used cutting tools (saws, abrasive discs, etc.), filters, abrasive (during the mechanical decontamination), etc. Figure 10 demonstrates the distribution of the secondary waste masses by the disposal routes in both alternative cases. When decontamination is not performed (Figure 10, A2 alternative), the mass of VLLW secondary waste is four times smaller than when decontamination is performed. The biggest share of the VLLW secondary waste for A1 alternative is composed of the used abrasive and a layer of the removed metal. Also it can be noticed that when decontamination is not performed, L/ILW secondary waste mass (waste that are transported to B3 complex) is almost two times lower.

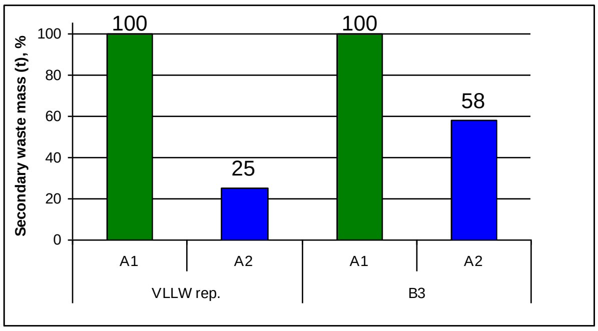

Figure 10: Secondary waste disposal ways for different alternatives

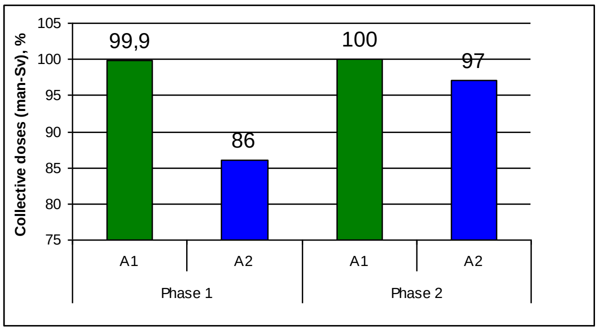

Figure 11: Workers collective doses for different alternatives

Analysis of workers collective doses (Figure 11) has shown that in Phase 1 for alternative A1 doses are 14 % higher. In Phase 2 collective doses are almost the same for both alternatives. This is mainly because those decontamination activities are mainly done in Phase 1.

After evaluating both alternatives it was defined that Phase 1 lasts longer than Phase 2. The difference is mostly determined by the dismantled components mass that is approximately 13 % smaller in Phase 2 (see Figure 2 for comparison) than in Phase 1.

When decontamination is not performed (Figure 12; A2 alternative), duration of Phase 1 is only 3 % shorter in comparison to the case when decontamination is performed (Figure 12; A1 alternative). It happens because the decontamination of the components during A1 alternative is performed simultaneously with dismantling and thus the duration of the project is almost the same. Also minor (~6 %) duration differences occur between the two alternatives during Phase 2. Obviously, the duration of Phase 2 is shorter when no decontamination is performed (see Figure 12; A2 alternative, Phase 2).

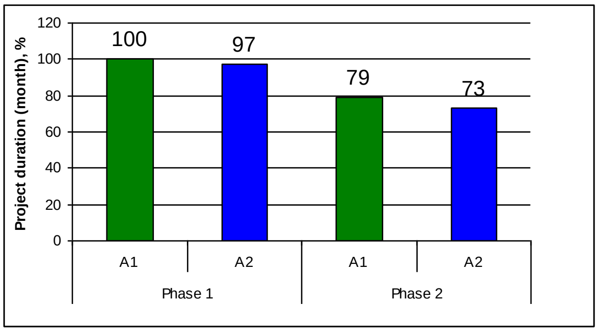

Figure 12: Project duration in months

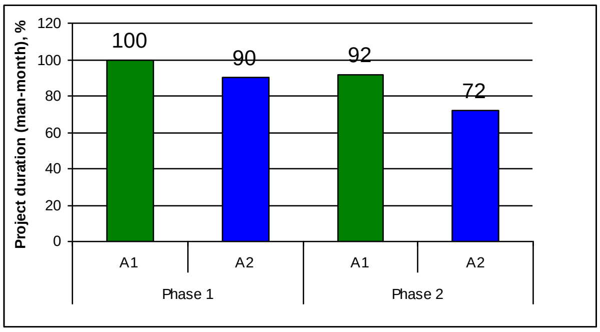

Figure 13: Project duration in man-months

Figure 13 demonstrates the comparison of the project duration expressed as man/day criterion. In this case the duration is also shorter when decontamination is not performed, but the difference by man/day is not that significant as by months. The difference in this case between A1 and A2 alternatives is only 10 % in Phase 1 and 20 % in Phase 2.

Before the beginning of V1 building dismantling, certain equipment (lifts, cutting, decontamination, radiological measurements and electrical equipment, containers for waste disposal and transportation, etc.) must be purchased to assure quick and effective performance of the work. The analysis of the investment necessary to purchase the equipment for D&D activities has shown that when decontamination is not performed (Figure 14; A2 alternative), the investments are only 6 % lower compared to the case when decontamination is performed (Figure 14; A1 alternative).

The minor difference is determined by the fact that during A2 alternative it is necessary to purchase more containers (i.e., half-height ISO containers) suitable for the disposal of the waste at VLLW repository. For A2 alternative there is no need to purchase the equipment for decontamination, however the price for the equipment is very similar to the price for the half-height ISO containers, thus the investments differ slightly. All other equipment (lifts, cutting, decontamination, radiological measurements and electrical equipment, etc.) is necessary for both dismantling alternatives.

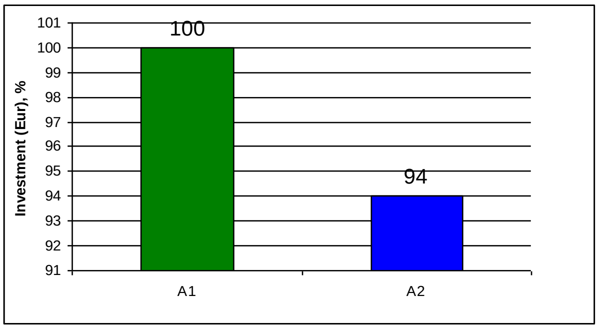

Figure 14: Investment

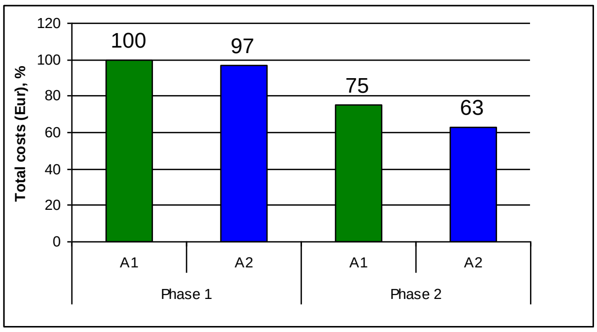

Figure 15: Total costs

Also an assessment of the distribution of overall expenses for D&D activities for both phases was performed. The expenses for Phase 2 are considerably lower than those for Phase 1. There are two reasons for this difference:

- The duration of Phase 2 is shorter than of Phase 1 (because of the smaller mass of the dismantled equipment), thus this determines lower consumption hot and cold water, safety clothes, electric power, wages, etc. and lower related expenses;
- All the necessary equipment is purchased during Phase 1.

The expenses of A2 alternative in Phase 1 are only slightly lower (~3 %) than the expenses for A1 alternative in Phase 1 (Figure 15). This happens because higher expenses are necessary for bigger amount of waste to be disposed at VLLW repository and thus the total expenses for both dismantling alternatives differ slightly. Some larger difference (~12 %) is between the alternatives for Phase 2.

The calculation of the total expenses (including the expenses for waste disposal at the repository) of the project shows that when no decontamination is performed (A2 alternative), the expenses are only 7 % lower than when decontamination is performed (A1 alternative).

4.2 MCDA results

As it was indicated above AHP method was applied in this report. Five experts participated in the pairwise comparisons of criteria, sub-criteria and alternatives performance against qualitative sub-criteria. The results of criteria weighting and consistency ratios (CR) based on experts evaluation are presented in Table 4.

Table 4: Criteria weights

Criteria	Expert 1		Expert 2		Expert 3		Expert 4		Expert 5	
	Weight	CR	Weight	CR	Weight	CR	Weight	CR	Weight	CR
S1	0.2508	1 %	0.1600	0 %	0.3451	1 %	0.1458	1 %	0.1229	2 %
E1	0.2508		0.1600		0.1762		0.2915		0.2945	
D1	0.1096		0.0400		0.1762		0.0498		0.0550	
T1	0.0460		0.0221		0.0678		0.0498		0.0521	
W1	0.2508		0.2980		0.0965		0.1316		0.1552	
E2	0.0460		0.1600		0.0869		0.2915		0.2795	
S2	0.0460		0.1600		0.0513		0.0400		0.0408	

As a working rule of AHP, a CR value of 10 % or less is considered acceptable. Otherwise it is recommended that matrix be re-evaluated to resolve inconsistencies in pairwise comparisons [5].

It is possible to notice that the biggest weights are assigned for safety (S1), economical (E1), waste streams (W1) and environmental (E2) criteria. Thus, these criteria have biggest impact to final alternatives ranking.

Each of the criteria has several sub-criteria as all the criteria belong to hierarchical structure. The results of sub-criteria weighting and CR based on experts evaluations are presented in Table 5.

Table 5: Sub-Criteria weights

Sub-Criteria	Expert 1		Expert 2		Expert 3		Expert 4		Expert 5	
	Weight	CR	Weight	CR	Weight	CR	Weight	CR	Weight	CR
S1.1	0.6667	0 %	0.5000	0 %	0.7500	0 %	0.5000	0 %	0.6667	0 %
S1.2	0.3333		0.5000		0.2500		0.5000		0.3333	
E1.1	0.1488	7 %	0.1618	0 %	0.4000	0 %	0.4286	0 %	0.2051	2 %
E1.2	0.7854		0.7510		0.4000		0.4286		0.7167	
E1.3	0.0658		0.0872		0.2000		0.1428		0.0782	
D1.1	0.5000	0 %	0.3333	0 %	0.8889	0 %	0.2500	0 %	0.25	0 %
D1.2	0.5000		0.6667		0.1111		0.7500		0.75	
T1.1	0.1939	6 %	0.1025	0 %	0.2684	6 %	0.4000	0 %	0.3325	0 %
T1.2	0.0633		0.2158		0.1172		0.2000		0.1396	
T1.3	0.7429		0.6817		0.6144		0.4000		0.5278	
W1.1	0.7306	6 %	0.7626	0 %	0.3667	5 %	0.4000	0 %	0.6000	0 %
W1.2	0.0810		0.0611		0.0513		0.4000		0.2000	
W1.3	0.1884		0.1763		0.5820		0.2000		0.2000	
E2.1	0.3081	0 %	0.1684	2 %	0.3571	0 %	0.3506	0 %	0.3546	3 %
E2.2	0.3081		0.1933		0.3571		0.3506		0.3546	
E2.3	0.1388		0.1527		0.0405		0.0461		0.0612	
E2.4	0.0675		0.3063		0.0907		0.1115		0.1018	
E2.5	0.0387		0.0313		0.0405		0.0471		0.0365	
E2.6	0.1388		0.1480		0.1141		0.0941		0.0913	
S2.1	0.5000	0 %	0.3333	0 %	0.6667	0 %	0.8000	0 %	0.6667	0 %
S2.2	0.5000		0.6667		0.3333		0.2000		0.3333	

It is possible to notice that the biggest weights are assigned for radiological worker safety (S1.1), total costs (E1.2), primary waste ratio (W1.1), radiological impact-man (E2.1) and radiological impact – environment (E2.2) sub-criteria. Thus, these sub-criteria have biggest impact to final alternatives ranking.

The judgement of dismantling alternatives against each other by comparing their performance on each qualitative sub-criteria based on different experts pairwise comparisons can be seen in Table 6.

Table 6: Alternatives performance against qualitative Sub-Criteria

Sub-Criteria	Expert 1		Expert 2		Expert 3		Expert 4		Expert 5	
	A1	A2	A1	A2	A1	A2	A1	A2	A1	A2
S1.2	0.50	0.50	0.50	0.50	0.50	0.50	0.67	0.33	0.50	0.50
E1.3	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
T1.1	0.50	0.50	0.50	0.50	0.50	0.50	0.67	0.33	0.50	0.50
T1.2	0.33	0.67	0.50	0.50	0.50	0.50	0.67	0.33	0.67	0.33
T1.3	0.25	0.75	0.25	0.75	0.25	0.75	0.67	0.33	0.67	0.33
E2.1	0.83	0.17	0.86	0.14	0.90	0.10	0.88	0.13	0.89	0.11
E2.2	0.83	0.17	0.83	0.17	0.90	0.10	0.88	0.13	0.88	0.13
E2.3	0.33	0.67	0.33	0.67	0.50	0.50	0.33	0.67	0.20	0.80
E2.4	0.50	0.50	0.50	0.50	0.50	0.50	0.33	0.67	0.25	0.75
E2.5	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
E2.6	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
S2.1	0.67	0.33	0.67	0.33	0.88	0.13	0.88	0.13	0.88	0.13
S2.2	0.50	0.50	0.50	0.50	0.83	0.17	0.50	0.50	0.50	0.50

Experts are not used to evaluate alternatives performance against qualitative sub-criteria, therefore normalized weights of quantitative sub-criteria values (calculated by DECRAD) for dismantling alternatives can be seen in Table 7.

Table 7: Alternatives performance against quantitative Sub-Criteria

Sub-Criteria	A1	A2	Sub-Criteria	A1	A2
S1.1	0.46	0.54	D1.2	0.41	0.59
E1.1	0.48	0.52	W1.1	0.70	0.30
E1.2	0.48	0.52	W1.2	0.50	0.50
D1.1	0.48	0.52	W1.3	0.24	0.76

Final ranking of dismantling alternatives is shown in Figure 16. The assessment performed using the AHP method of Multi-Criteria Decision Analysis has shown that A1 alternative (decontamination is performed) with 0.5469 final ranking is better than A2 alternative (no decontamination is performed) with 0.4531 final ranking. Thus the A1 alternative is recommended as the better option for the dismantling of Ignalina V1 building equipment when mostly very low level waste is generated.

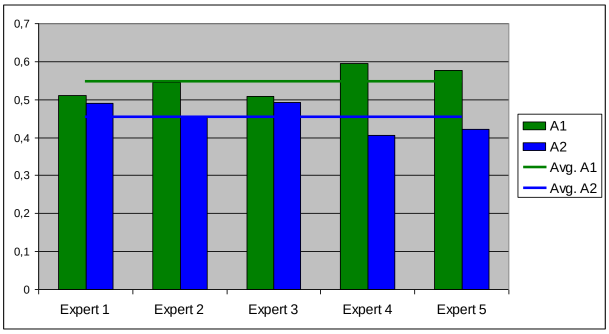

Figure 16: Final ranking of dismantling alternatives

5 Conclusions

V1 Building components could be classified as very low level waste (VLLW). exempt waste (EW) and low/intermediate level waste (L/ILW) with sealed spend sources (SSS). 60 %. 39 % and less than 1 % respectively.

In Phase 1 the mass of primary EW is almost two times higher when decontamination is performed (A1 alternative) compared to the case when no decontamination is performed (A2 alternative). 79 % and 40 % respectively. The mass of VLLW is 6 % when decontamination is performed and 45 % if decontamination is not performed.

In Phase 2 the mass of primary EW is almost two times higher when decontamination is performed compared to the case when no decontamination is performed. 98 % and 37 % respectively. The mass of VLLW is 1 % when decontamination is performed and 62 % if decontamination is not performed.

The mass of secondary VLLW is four times smaller if no decontamination is performed compared to the case when it is performed (100 % and 25 % respectively). and the mass of L/ILW is only 1.7 times lower (100 % and 58 % respectively).

Total duration of the project. investment necessary for the project and total project costs for both alternatives are similar (difference is less than 10 %).

The assessment performed using the AHP method of Multi-Criteria Decision Analysis has shown that A1 alternative (decontamination is performed) is better than A2 alternative (no decontamination is performed). Thus the A1 alternative is recommended as the better option for the dismantling of Ignalina V1 building equipment when mostly VLLW is generated.

6 References

1. Siempelkamp. NiS Ingenieure mbH CORA-CALCOM. Brochure. http://www.siempelkamp-nis.com/fileadmin/pdf/en/Cora_Calcom_GB_0408.pdf.
2. V. Daniska and V. Necas. Modelling of the decommissioning process of nuclear installations. Journal of Electrical Engineering 51 (5–6) (2000). pp. 156–167.
3. Yukihiro Iguchi. Yoshiki Kanehira et al. Development of decommissioning engineering support system (DEXUS) of Fugen nuclear power station. Journal of nuclear science and technology. Vol. 41. No. 3. p. 367-375. 2004.
4. The software DECRAD validation report. TA-14-13.10. LEI. Nuclear engineering laboratory. 2010
5. Saaty. T. L. (1994). Fundamentals of Decision-Making and Priority Theory with the AHP // RWS Publications. Pittsburg. PA. USA.